A PRELIMINARY INVESTIGATION OF TWO SMALL-SCALE, AUTONOMOUS WIND-HYDROGEN SYSTEMS

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Abstract

The use of renewable energy systems to supply electrical power in remote, off-grid areas is fairly well established throughout the world. Small-scale applications in the U.S. include such sites as construction warning signals, telecommunication stations, highway rest areas, single-homes, science research stations, National Park facilities, and small villages. Depending on the resource available, such systems typically rely on photovoltaic (PV) modules and/or wind turbines as the primary power source, and usually employ batteries or diesel generators for back-up power. The recent advent of hydrogen fuel cell technology has presented a new back-up power option for such applications, although costs remain high as the technology advances. In this investigation, we examined the technical feasibility of two small-scale, autonomous systems that include wind and fuel cell power generation and the conditions in which they are economically competitive. The optimization software, HOMER was used to model and evaluate these systems.

Introduction

In the continuing effort to become less dependent on foreign sources of energy fuels, the United States spends significant time and money researching and implementing renewable energy resources such as solar, wind, biomass, etc. The cost of wind-generated electricity has continued to decline significantly over the past 20 years due to improvements in technology that have resulted from such research, as well as the increased utilization of grid-tied wind-farm generated power, programs such as "Wind Powering America", and various motivators such as net-metering and tax incentives.

In particular, remote areas that are not connected to an electrical power grid can benefit greatly from renewable energy supplies. Such locations generally have the following characteristics:

- lack of utility infrastructure and/or a high cost to extend or upgrade the electric grid for basic electric service
- high cost of delivered fuel for conventional fossil fuel electric generation
- low level of reliability of the current electric generation system
- good wind or solar resource

Most remote, off-grid PV or wind generation systems incorporate batteries or diesel engines for backup power. In a wind-battery system, for example, batteries are charged using surplus power generated during excess wind events (high-wind or low load intervals).

In the past five years, with the growth of fuel-cell technology (primarily in support of the automotive industry), the storage of excess wind energy as hydrogen has emerged as an intriguing alternative to established back-up power systems. The logic for a basic wind-hydrogen system is as follows: when excess wind energy is available, power is supplied to an electrolyzer (hydrogen-generator), which consumes water to generate hydrogen, which is then stored as a compressed gas. During deficit wind events, a fuel cell then utilizes the stored hydrogen to produce electricity and meet the load.

Because fuel cells are still a largely experimental technology, the costs for wind-hydrogen applications are relatively high when compared with wind-battery and wind-diesel systems. Various cost-of-energy (COE) studies for integrated renewable fuel-cell systems have been produced over the past several years[1-3]. The purpose of this investigation is to add to the studies by providing preliminary models of two small-scale wind-hydrogen systems, and to offer general speculation as to the conditions in which they might be economically competitive.

The optimization software used for this effort was HOMER (Hybrid Optimization Model for Electric Renewables). HOMER is a simple modeling system that performs comparative economic analyses on proposed and actual distributed generation power systems. (HOMER can be downloaded from: www.nrel.gov/international/homer .) For a particular application scenario, inputs to HOMER include load data, renewable resource data, system component specifications and costs, and various optimization information (e.g. number of components, percentage of unmet load, etc.). Furthermore, HOMER can perform "sensitivity analyses," where the values of certain parameters (e.g. fuel cell cost) can be varied to determine their impact on the COE for the system in question.

Method of Analysis

Scope

Two small-scale scenarios were investigated. The first was a PV/Battery powered radio repeater located east of Prineville, Oregon; the second was the small, remote, diesel-powered village of Wales, Alaska. Details of each scenario are provided below.

Approach

Load and resource data for the sites were first acquired, followed by existing system costs. The systems were then modeled in HOMER to determine existing COE. Next, costs for the hypothetical systems were estimated and modeled for current day (2002), + 5 years (2007) and + 10 years (2012).

Load & Resource Data

Electrical load data from the sites were available, as was renewable resource data from at or near the sites. Specific information is provided in the scenario descriptions below.

Component and System Costs

Key component and system cost estimates are provided in Tables 1 and 2. Shipping and installation cost estimates are included. A 3 % annual inflation rate was employed for "stable" cost items (i.e. mature technologies such as batteries).

Photovoltaic (PV) Modules. The installed PV array cost for the existing repeater site was about \$12/watt; costs of \$8/W installed were used for future predictions[4]. Lifetimes were taken to be 20 years.

Wind turbines. The wind-turbine market is well established; turbine system performance and cost data were obtained from the manufacturers[5]. Lifetimes are assumed to be 20 years.

Inverters/Rotary Converters. In the repeater scenario, an inverter is necessary when using a DC wind turbine, so that power can be supplied to the electrolyzer. Efficiency data was taken from manufacturers specifications and was factored in with the efficiency rating of the electrolyzer, where available. An average cost of \$950/kW was used[5], with a realistic lifetime of about 10 years[6]. For the remote village scenario, a rotary converter was preferred over an inverter due to maintenance capabilities of local crews[7].

Water. Feed water and cooling water are required for the electrolyzer. To avoid poisoning the electrolyzer, feed water should be purified. Small, remote systems (e.g. telecomm) may use a storage tank; larger systems (e.g. rest areas, homes) can draw from existing water lines. Water treatment systems need regular maintenance (e.g. filter cartridge replacement).

Electrolyzers. Several varieties of industrial electrolyzers are currently available, but small-scale systems are underdeveloped. The current cost of industrial systems is approximately $1500/kW; this figure was arbitrarily doubled for small systems, so a cost of $3000/kW was used, with projected costs of $1000/kw in the near term and $500/kW within ten years[8]. Also, hydrogen production pressures have been low (100-200 psi), thereby requiring compressors for high-pressure storage. However, 2,500-3,000 psi production pressures have been demonstrated recently and are expected to be in production in the very near future[9]; targets are upwards of 6,000 psi. This will eliminate the need for compressors, so compressors were not included in this study.

Hydrogen storage. Hydrogen storage technology is evolving rapidly. Hydrogen can be stored several different ways – as a compressed gas, as a liquid, as a metal hydride, etc. Compressed gas storage is currently the most cost-effective, and so was considered for this work; small quantity prices are around $230/kg for a 5,000 psi tank, with long term targets of around $60/kg[10].

Fuel cells. Fuel cell technology is also evolving rapidly. Current costs for small-scale applications are approximately $1,500/kW and are targeted to drop below $500/kW once high-volume production begins[11]. Lifetimes are quoted as 30,000-40,000 hours, with efficiencies from 50-80%[11].

Batteries. Costs for deep-cycle batteries are relatively low, stable, and readily available; lifetimes are 5-10 years, depending on cycling.

Diesel generator sets. The costs for new diesel generators are well established and range from $250-$500 per kW of rated capacity[12]. Diesel generator sets may require a significant amount of labor and materials to maintain proper operation. Costs for regular maintenance can be high depending on maintenance schedules; for the small village scenario, a cost of $5.00 per hour of operation was used, with an operating lifetime of 10,000 hours[13].

Diesel fuel. Diesel fuel prices vary widely. Villages like Wales buy large quantities (since waterways are iced over much of the year) and can get reasonable prices ($1.28/gal delivered)[13]. Costs for storage, tank replacement, and spill clean-up were not included.

Operation & Maintenance (O&M). O&M costs can be highly variable and were difficult to determine. Per annum estimates were used.

Balance of System (BOS). BOS costs (aka "system fixed capital cost") include miscellaneous costs that can't be ascribed to one particular component, but are associated with the system as a whole. Examples include road construction, site preparation, system controllers, equipment housing, etc. Available data were used.

Cost of Energy (COE). COE is calculated as total capital cost plus fixed capital return plus annual O&M, all divided by annual energy production.

Scenario 1: VHF Radio Repeater Station, Prineville, Oregon

This is a 350 watt PV-battery powered system located east of Prineville, Oregon (44° 20' N, 120° 50' W). This system was modeled with a wind-turbine and fuel cell system added to the existing system.

Load. Load data was obtained from the system specifications[14]. The station has an annual average DC load of 1.182 kW/d (summer (April through September) average = 1.716 kWh/d, winter (October through March) average = 0.652 kWh/d), with a maximum hourly load of 252 watts (peak current draw = 21 A), excluding parasitic loads. The daily load profile was not available, so it was estimated. Daily and hourly noise values of 10% were estimated.

Resources. Solar radiation and clearness data for this site were taken from nearby Pendleton, Oregon (45° 40'N)[15]. The annual average global radiation is 4.15 kWh/m^2/day, with an annual average clearness index of 0.573. Hourly wind resource data for the site was unavailable, but it is located in a Class-1 wind regime, so data from nearby Pendleton, OR (also a Class-1 regime) was used[16]. The average wind speed is 3.5 m/s (Weibull-k value = 1.67).

Components. This scenario was modeled with 0.35 kW PV panels, Bergey Excel 1 kW turbines, Trojan L-16 Batteries, a Trace DR1524 inverter, a Proton PEM electrolyzer, Quantum hydrogen tanks, and Plug Power fuel cells. Table 1 contains the key component and system capital costs.

Optimization. Because power system reliability is critical for most communication systems, a solution constraint of 1% unserved power was used in this model. Sensitivity studies were performed on wind speed (up to 7 m/s), PV capital cost, and fuel cell system capital cost.

Scenario 2: Village of Wales, Alaska

Wales is the westernmost village of North America with a population of about 160. In 2000, it was retro-fitted from a diesel system to a wind-diesel hybrid system. A fuel-cell system was included in the model.

Load. 15-minute time series data obtained in Wales (65° 37'N, 168° 05'W) from November 1993 through October 1994[17] was converted to hourly data. The village has an annual average load of 1638 kWh/d (68.3 kW), with a maximum of 134.3 kW, and daily and hourly noise of 8.5%.

Resources. The solar resource is poor, because of the high latitude. For this reason, PV was not considered as a reasonable alternative for this scenario. Solar radiation and clearness data were obtained from nearby Nome (64° 30'N, 165° 30'W); the annual average global radiation is 2.45 kWh/m^2/day, with an annual average clearness index of 0.337. Wind data were also taken from a 15-minute time series[17]. The village is in a Class 7 wind regime, with an average wind speed of 8.7 m/s (Weibull-k value = 2.25).

Components. Table 2 contains key component and system capital costs. When applicable, system costs were taken from previous work[13].

Optimization. Sensitivity studies were performed on wind speed (down to 4 m/s), fuel cell system capital cost, and diesel fuel price.

Table 1 – Key Component Costs: Radio Repeater, Prineville, OR

Bold items are HOMER input values.

	2002	**+ 5 years**	**+ 10 years**
PV system cost (per kW)	11,900	8,000	4,000
PV system cost	**4,410**		
Battery bank cost	**4,524**		
Turbine hardware cost	3,155	3,657	
Turbine shipping and set-up cost	530	614	
Turbine system cost, total	**3,685**	**4,271**	
+Inverter hardware, S&H cost	1,000		
Inverter efficiency (@1kW)	0.9		
+Feed water tank cost	200		
+Feed water treatment system cost	500		
Electrolyzer H2 output (kg per h/psi)	/200	/1,000	/5,000
Electrolyzer efficiency	0.76		
Electrolyzer peak load (kW)	1		
Electrolyzer system cost (per kW)	3,000		
+Electrolyzer system, S&H cost	3,100		
H2 storage tank size (kg)	3		
H2 storage tank pressure (psi)	200	1,000	5,000
+H2 storage tank, S&H cost	750	300	100
Fuel cell peak output (kW)	1		
Fuel cell average efficiency	0.5		
Fuel cell cost (per kW)	3,000	1,000	500
+Fuel cell, S&H cost	3,100	1,100	600
Fuel cell system cost	**8,650**	**4,200**	**3,000**
Fuel cell O&M cost ($/hr)	**0.01**	**0.01**	**0.01**
Site preparation	3,000		
Housing: electrolyzer, fuel cell, etc.	1,500		
Controller	500		
System fixed capital cost	**5,000**		
System O&M cost	**150**		

Table 2 – Key Component and System Costs: Wales, Alaska

Bold items are HOMER input values.

	2002	**+ 5 years**	**+ 10 years**
Turbine hardware cost (50 kW)	65,000	65,000	65,000
Turbine shipping and set-up cost	45,000	45,000	45,000
Turbine system cost, total	**110,000**	**110,000**	**110,000**
Turbine O&M cost (@$0.015/kWh)	**3,000**	**3,000**	**3,000**

Rotary converter (100 kW)	**55,000**	**55,000**	**55,000**
Battery bank cost (31.2 kWh)	**43,500**	**43,500**	**43,500**
Battery O&M cost	**200**	**200**	**200**
Inverter system cost (150 kW)	**112,500**	**112,500**	**112,500**
Inverter efficiency (@1kW)	**0.9**	**0.9**	**0.9**
Inverter O&M cost	**20?**	**20?**	**20?**
Electrolyzer H2 output (slpm/psi)	/200	/1,000	/5,000
Electrolyzer efficiency	0.76	0.76	0.76
Electrolyzer peak load (kW)	1	1	1
Electrolyzer system cost (per kW)	3,000	1,000	500
Electrolyzer system cost	3,000	1,000	500
Electrolyzer S&H, set-up cost	300?	300?	300?
Electrolyzer system cost, total	3,800?	3,800?	3,800?
Electrolyzer O&M cost	50?	50?	50?
H2 storage tank size (kg)	1	1	1
H2 storage tank pressure (psi)	200	1,000	5,000
H2 storage tank cost	1,000?	700?	500?
H2 storage tank S&H cost	50	50	50
Fuel cell peak output (kW)	1	1	1
Fuel cell cost/kW	3,000	1,000	500
Fuel cell cost	3,000	1,000	500
Fuel cell average efficiency	0.5	0.5	0.5
Fuel cell S&H cost	300	300	300
H2 storage/Fuel cell system cost	4,350?	2,050?	1,350?
H2 storage/Fuel cell O&M cost	100?	100?	100?
Diesel generator rated power (kW)	1	1	1
Diesel generator cost	500	500	500
Diesel generator S&H cost	50	50	50
Diesel generator O&M cost ($/hr op.)	5	5	5
Power electronics cost/kWp to load			
Power electronics total cost			
Site preparation	2,000?	2,000?	2,000?
Water processing equipment	500?	500?	500?
Housing: electrolyzer, fuel cell, etc.	1,000	1,000	1,000
Controller and DAQ	5,000	5,000	5,000
System fixed capital cost			
System O&M cost			
Overall system efficiency			
Maximum storage time (days)			
Cost of energy ($/kW)			

Results & Discussion

Scenario 1: VHF Radio Repeater

HOMER calculated the COE for the existing site to be $2.08/kWh.

Scenario 2:

Conclusion

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